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The Declining Even Flow Effect in the National Forest Planning Process

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Abstract

McQuillan (1986) has identified what may be a serious flaw in the planning process used by the USDA Forest Service. The problem, which McQuillan called the declining even flow effect (DEFE), can occur during repeated iterations of a planning process using a timber harvest scheduling model whose objective is wealth maximization subject to nondeclining yield constraints. The DEFE creates a situation in a sequence of plans over time where the first-period harvest level declines below that attained for previous planning iteration analysis. This report addresses the relationship between the process used by the Forest Service to develop FORPLAN models and the DEFE. An example using Kootenai National Forest planning documents illustrates the highly constrained nature of Forest Service planning models. The effect of these constraints and other characteristics of FORPLAN models on the DEFE is examined. Two items common to nearly all forest planning models—a land base that is not entirely old-growth and constraints to assure that the 40-acre clearcut limit is not violated—caused a large reduction in the DEFE observed in a FORPLAN version of McQuillan's case study model. However, one characteristic of Forest Service planning models, the use of intermediate harvest options, which plausibly could have reduced the DEFE, did not. The opportunity cost associated with imposing a first-period harvest floor to eliminate the DEFE was also evaluated. The major conclusion of the study is that the regulations, initial conditions, and the FORPLAN model formulations all tend to reduce the likelihood and magnitude of the DEFE.

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INTRODUCTION

The Forest Service is currently nearing completion of the first iteration of planning mandated by the National Forest Management Act (NFMA) of 1976 (P.L. 94–588). After the press of deadlines and the conflict created by specific resource decisions has abated, an important extension to the planning process will be to evaluate the planning approach applied and, specifically, the analytical methods used. Much of the recent technical literature concerning the use of linear programming in harvest scheduling models has dealt with topics that are central concerns of the forest planning process (e.g., Hof et al. 1986, 1988; Hoganson and Rose 1987; Paredes and Brodie 1988; Pickens and Dress 1988).

The research presented in this report addresses a paradoxical phenomenon originally identified and demonstrated by McQuillan (1986), which he called the declining even flow effect (DEFE); namely, a planning process that is repeated periodically (e.g., every 10 years in the Forest Service case) and is conducted using a harvest scheduling model with a wealth (present net value) maximizing objective and nondeclining yield constraints does not generally lead to a nondeclining sequence of timber harvests. The divergence from nondeclining yield occurs when the forest plan is revised and the chosen harvest level in the first cutting period is less than the harvest implemented under the previous plan. The DEFE would be expected to be most severe for a forest made up entirely of old-growth stands. Under this scenario, the model would choose to harvest the most profitable stands early in the planning horizon, while deferring harvest on less profitable stands until later. This harvesting sequence is dictated by the low or negative growth rate of old-growth stands, the effect of discounting, and the opportunity cost associated with highly productive lands being occupied by stands with little or no growth.

In addition, it is likely that unprofitable stands will be scheduled for harvest at some point in the future to satisfy the nondeclining yield constraints. This occurs because the discounted cost of scheduling negatively valued stands several decades into the future is more than offset by the increased value associated with harvesting the higher valued stands during the early periods of the planning horizon. Essentially, the model can choose to bridge the gap between accelerated early harvest of profitable existing stands and future harvest of regenerated stands with timber that cannot be harvested at a profit.

The declining harvest level between time periods occurs when the forest plan is revised during a future iteration of planning. At this point, some of the profitable harvests have been implemented, which leaves less short-term gain to be balanced against future losses resulting from cutting unprofitable stands. This leads to a first-period harvest calculated for the revised plan that is less than the harvest in the previous cutting period. Thus, the Forest Service is presented with two options, either (1) to incur unplanned, immediate, and repeated departures, or (2) to place a floor on first-period timber harvest that will lead to harvest levels higher than the economics in the harvest scheduling model would otherwise indicate. Either option is difficult to defend, and the option of repeatedly applying a constraint on first-period harvest would lead to the early harvest of the negatively valued stands in some later planning iterations. The concern for the agency as it concludes the first iteration of planning is the extent of the DEFE that can be expected as future iterations of planning and analysis are conducted.

The Forest Service planning process is distinctly different from the situation presented in the case study and discussion of McQuillan in three ways. The first and most important difference is that McQuillan considers a timber only, profit-oriented enterprise with nondeclining yield constraints, while the multiple-use requirements of the Forest Service planning process result in the imposition of numerous additional constraints on the individual FORPLAN models. Although these constraints vary widely from model to model, certain requirements are represented similarly in most models and may affect the DEFE. In addition, special constraints are often applied to address specific issues on each forest, and these constraints may also affect the DEFE. Examples include constraints imposed to meet management requirements for a wide range of predominantly nonmarket concerns (e.g., sediment, erosion, scenic attributes), endangered species (e.g., grizzly bear, spotted owl), and those designed to address multiple-use issues specific to a forest (e.g., wilderness areas, recreational development).

The second distinction between McQuillan's (1986) case study and forest planning models is the set of options available for management of the land base. McQuillan considered only clearcutting prescriptions with no intermediate cuts or alternative regeneration harvests. However, in many forest planning models used by the Forest Service, shelterwood and selection options are also considered. In addition, thinnings are incorporated in many prescriptions, and these intermediate cuts can result in increased flexibility for satisfying nondeclining yield constraints within a given model. It is not immediately clear if the presence of intermediate cuts will increase or reduce the DEFE—this depends on

the economic characteristics of the thinnings, the relative numbers of positively and negatively valued stands available, and the magnitude of present net value associated with the timber land base. One final consideration is that, even though a specific stand may be quite valuable, harvesting on certain lands may either be spread over several periods or delayed until later periods because of considerations such as road access.

The third difference between McQuillan's (1986) example and an average forest planning application is the age structure of the initial forest. McQuillan considered a forest that was entirely old-growth, an age structure never encountered in national forests. Most forests have been managed in the past to some extent, and the implicit goal of previous management was to regulate the forest. This goal resulted in forests where the commercial forest base has undergone harvesting for several decades. Although the areas harvested would be expected to be somewhat smaller than those resulting from regulation via area control, substantial portions in many cases have already been converted from old-growth to managed stands. In addition, ecological perturbations such as forest fires and pathogen infestations often add age diversity to the as yet unmanaged portion of the forest. As can be seen in Hof et al. (1986), even relatively small shifts in initial age structure of the forest can result in significant shifts in land allocation when nondeclining yield constraints are applied.

FORPLAN MODEL FACTORS AFFECTING THE DEFE

The Highly Constrained Nature of FORPLAN Models

To help understand the highly constrained nature of forest planning models developed using FORPLAN, consider the following example based on the Kootenai National Forest planning analysis. Figure B-14 (Haugen 1987) of the forest's planning document will be used to facilitate this discussion and is reproduced here as figure 1. This figure presents the changes in present net value observed when required sets of constraints are added and removed during the process of FORPLAN model development. Concentrating on the central portion, our analysis starts with an unconstrained model solution having a present value of $2,083 million, and progresses down the page to alternative A with a present value of $1,143 million, indicating that the constraints needed to represent Forest Service regulations in the analysis collectively reduce present value by 45%. Thus, such factors as nondeclining yield, restricting regeneration harvests to occur at or after 95% of culmination of maximum mean annual increment, and minimum management requirements (MMR's) have a large influence on the forest's management. However, the important question is whether the DEFE is likely to be fundamentally changed by the constraints applied, or whether the constraints simply reduce the DEFE in proportion to the reduction in harvest levels.

Our discussion focuses on the minimum management requirements applied to this model and on their expected impact on the DEFE. The first MMR applied related to grizzly bear habitat maintenance, which required leaving large areas undeveloped. If the model was allowed to select the location of these areas, lands with poor timber economic potential would likely be allocated to this use because of the wealth-maximizing objective. This would decrease the number of negatively valued stands available in later periods for balancing early profitable harvests. Because this "balancing" is the main cause of the DEFE, these constraints have the potential to reduce both its size and magnitude.

The next MMR's considered in figure 1 address soil and water issues. These restrictions on land use have a very high opportunity cost of $566 million. Many of the restrictions in this class would involve either restrictions on certain lands (e.g., stream buffers restricted from harvest) or restrictions concerning spatial and temporal applications of allowable timber management practices (e.g., spatial and temporal separation of harvesting activities). These restrictions have the potential to significantly reduce the DEFE, because the spatial and temporal limitations would prevent a contiguous block of sensitive land from being completely harvested in a single cutting period (decade). Although specific analysis areas in many FORPLAN models are not necessarily contiguous, they generally contain large contiguous areas. The constraints would tend to spread the harvests out over several cutting periods on these areas. In addition, these sensitive areas would tend to be near streams, and are often comprised of high-value land whose early exploitation is required for a large DEFE. On the other hand, an examination of McQuillan's case study shows that most of each analysis area was clearcut in a single cutting period. Thus, his case study has far more opportunity to exploit the differences between stands than do forest planning models.

The magnitude of lost present net value associated with the final MMR category, old growth/diversity, is quite small ($31 million), and it is not clear if these constraints will reduce the DEFE.

The final point of interest in figure 1 is the reduction in present net value associated with application of nondeclining yield constraints. When these constraints are applied prior to the MMR's, a high opportunity cost is observed ($202 million), while the opportunity cost is much less when the constraints are applied after the MMR restrictions ($28 million). Clearly, in objective function value terms, the MMR restrictions impact harvesting in a way similar to that of nondeclining yield. This similarity arises primarily from the spatial and temporal dispersion of management actions imposed by the MMR restrictions. This would suggest that the DEFE would not be expected to be extreme in this example.

Note that the above discussion deals with the results of only one forest planning analysis and model. However, similar constraint sets are common to most forest planning models, and some of these constraints will always distribute the liquidation of contiguous forest units over time.

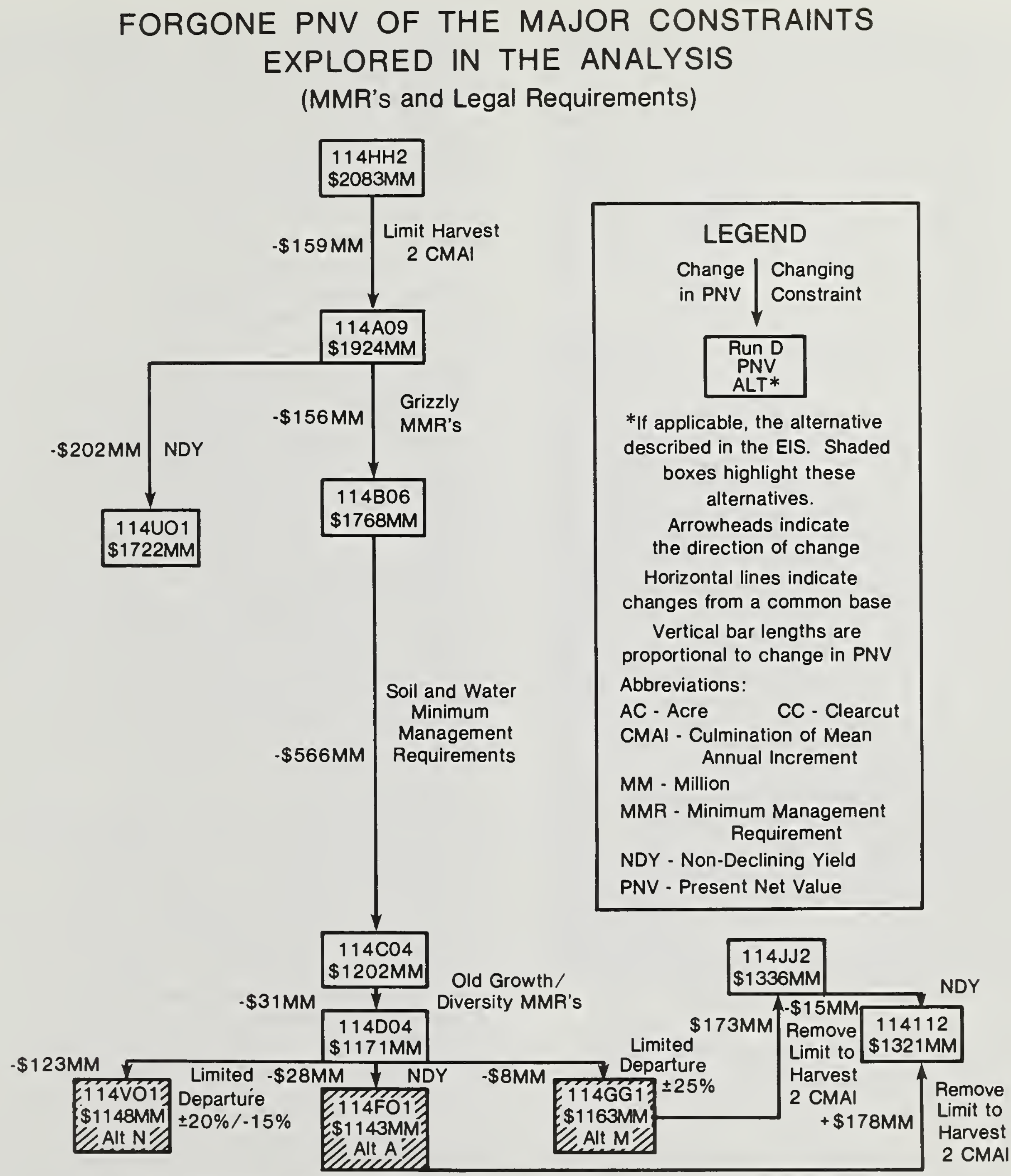

Figure 1.—Figure B-14 (part 1) from the Kootenai National Forest planning documents (Haugen 1987). This figure demonstrates the opportunity cost associated with constraint sets applied at various levels of the FORPLAN modeling process.

Additional Restrictions and Constraints with Direct Effects on the DEFE

There are other forest planning restrictions and constraints that affect the DEFE. Before running FORPLAN, planners are required to analyze the economic efficiency of alternative prescriptions on all classes of timberland. Lands considered uneconomical to harvest may be excluded at this time. In addition, the amount of negative value harvesting on any analysis area may be restricted in any given cutting period within FORPLAN models.[2]

[2] *Jim Merzenich of the Region 6 Regional Office indicated that these options or similar methods have been used in forest planning situations in Forest Service Regions 1 (Northern) and 6 (Pacific Northwest) to restrict the choice of negatively valued timber harvests in the future.*

Another reality of forest planning is that the current situation sometimes dictates much of what will be implemented in the first decade, and consequently, the planning process creates a framework where near-term options often are very limited. One example of near-term restrictions is the current extensive salvage and sanitation harvest of pine bark beetle mortality in many Rocky Mountain forests. Other examples are the explosion of Mount Saint Helens and the catastrophic fires of the summer of 1988. In such cases, management actions during the first decade are restricted to the point that DEFE is not a concern.

The only important constraints remaining to be discussed in terms of their impact on the DEFE are those included to assure that the maximum size of a regeneration harvest (e.g., clearcut, shelterwood, or seed tree) is 40 acres or less (100 acres or less in Alaska). These constraints appear in most FORPLAN models because they are required by the NFMA. They can be formulated in a variety of ways, the most common being to require that not more than a certain amount of each analysis area can be regeneration harvested in a certain cutting period. If analysis areas are spatially located in large contiguous blocks of land, this restriction is typically represented by constraining each analysis area so that not more than 25% of it can be regeneration harvested in any cutting period (decade). If the analysis areas occur in somewhat smaller blocks of land, then the area allowed to be regeneration harvested in any cutting period is increased somewhat. Note that not all of an analysis area need be in one contiguous block for this approach to be appropriate; it is sufficient for the analysis area to be comprised of several relatively large blocks. Some areas where regeneration and stand development are sufficiently slow require inclusion of either more restrictive constraints or more restrictive timber prescriptions to limit harvesting in a cutting period because of adjacent actions in previous or future cutting periods. These constraints, taken as a group, should significantly reduce the DEFE by rationing the harvest of each analysis area over several decades.

OPTIONS FOR SELECTING A CASE STUDY

Two very different options are available for developing a case study to assess the impact of the DEFE in forest planning:

1. Select one (or possibly more if resources permit) test case national forest FORPLAN model, and simulate the process of repeated iterations of planning with the model. This approach would be most useful for measuring the DEFE on the test case model.
2. Select a case study model that is considerably simpler than a real forest planning model, and simulate certain aspects of FORPLAN model development in order to measure their impact on the DEFE. This approach would be most useful for developing a more complete understanding of the relationship between the process of forest planning model development and the DEFE.

The main advantage of the first approach is that the study would be able to make a very specific statement concerning the magnitude of the DEFE for the selected forest. This advantage would, however, be purchased at a high price. Some of the studies done by the Policy Analysis Staff have used actual forest models successfully (e.g., Ashton 1985). Experience indicates that studies like this, where few data values are changed and feasibility cannot be violated, can be conducted in a straightforward manner. However, if extensive revision of the FORPLAN data sets is involved, the process becomes expensive, time consuming, and the completion of the project becomes problematical. Such would be the case if one were to iteratively simulate the implementation of forest plans over enough cycles of planning to understand the magnitude of the DEFE for a forest.

In addition to these general concerns, several specific questions must be addressed. First, in the selection of a test case model, should one attempt to select a case study which demonstrates an extreme potential for the DEFE, or one that has an average DEFE? Second, even if this concern is resolved, how does one identify which situation is present given the current level of understanding of the DEFE? Clearly, the constraints applied to the model will be important. The relationship of profitable and unprofitable harvests available is also an important factor. A study like the one proposed by the second option would help to resolve some of these uncertainties. In the final analysis, no matter which type of case study forest one selects, it still is a sample of only one observation, and thus any conclusions would be of limited applicability.

Even if these specific questions can be resolved, the technical problems associated with updating large FORPLAN data sets are formidable. Substantial changes to several sections of the input data would be needed. The land base would need to be entirely updated between runs in order to reflect the results of the activities conducted during the first period of plan implementation. This process would lead to a proliferation of both analysis areas and prescriptions, resulting in successively larger, more complex, and more expensive models. Yield streams and economic data would require updating. In addition, constraints are often applied for the first two cutting periods in FORPLAN models, and it is not clear how or if these constraints should be modified or eliminated as one proceeds through repeated simulation of planning cycles. Clearly, by the time all of the updating is done and certain assumptions of necessity are included in the updating process, it would be difficult to separate changes that occur because of these assumptions from changes that can be attributed to the DEFE.

The second option available to study the DEFE would directly address the question, What are the implications for the DEFE of the way FORPLAN models are formulated? Both the situations on forests and the FORPLAN models constructed to mathematically represent these situations are extremely variable. Also, it is clear that certain frequently used constraints, options, and existing conditions can significantly affect the magnitude of the DEFE. With the second option, a large number of

simulations would be possible with a small test case model, and the resulting analysis would have general applicability to the expected impact of situations (e.g., constraint sets) common in forest planning models. Additional advantages are that the cost would be low, and problems with ambiguity and assumptions associated with problem updating would be minimized. For these reasons, we selected the second option for this study.

CASE STUDY

Description

The case study model presented by McQuillan (1986) for the original analysis of the DEFE was selected as the standard of comparison for our analysis. The model contains five analysis areas, each with 1,000 acres and having identical site productivity and stocking. The prescriptions allowed are clearcutting and minimum level management. The forest currently consists of old-growth stands containing 15,000 board feet (mbf) per acre, and no net volume change is expected. In the model, regenerated stands are expected to have no volume until age 70, at which time the volume becomes 25 mbf per acre and does not change as the stands age. The price is currently $300 per mbf, but is expected to increase by 1.5% per year for the next 50 years, after which price will not change. The only difference between analysis areas is the cost associated with timber harvesting. The harvest costs are $170, $290, $410, $530, and $650 per mbf for analysis areas 1 through 5, respectively. These costs are assumed to be the same for both old-growth and regenerated stands. The discount rate is 4%, and all costs and revenues are assumed to occur at the midpoint of the cutting period. Land area, nondeclining flow, and a limit of harvest below an exogenously calculated long-run sustained yield level were the only constraints included in McQuillan's example. The objective was to maximize present net value over a 12-cutting-period planning horizon. Each cutting period is 10 years long.

Analysis areas 1 and 2 always provide positive value harvests; analysis areas 3 and 4 start with negative value harvests but become positive in the third and fifth decade, respectively, because of rising product value; analysis area 5 can never be harvested profitably. See McQuillan (1986) for a more complete financial analysis of the problem.

The same problem was formulated for this study using FORPLAN Version 2 (Johnson et al. 1986, Johnson and Stuart 1987, Robinson et al. 1987). Because of two differences between the harvest scheduling model used by McQuillan and FORPLAN, exact reproduction of McQuillan's results was not possible. First, both models employed a long-term sustained yield cap, but the methods used to calculate the cap were different. Second, there were minor discrepancies in the timing choices generated by the two models. This FORPLAN model will be referred to as the "base model."

Table 1 compares McQuillan's model and the base model for eight iterations or rounds of planning. The first-period harvest level is reported for each planning iteration for each model. The volume reduction observed for each occurrence of the DEFE (departure) is also reported. The main difference between the results of the base (FORPLAN) model and McQuillan's model are that two departures (in planning iterations 3 and 4) in McQuillan's model are replaced by one much larger departure in the base model (planning iteration 4). In addition, the base model has slightly greater total DEFE (ΣDEFE = 9,949 mbf) than McQuillan's model (ΣDEFE = 8,743 mbf). Otherwise, the two models provide very similar results.

Table 1.—First-period comparison of McQuillan's model and the base model developed using FORPLAN version 2 (volumes are mbf).

Planning iteration	FORPLAN base model		McQuillan model	
	Harvest	DEFE	Harvest	DEFE
1	10,000		10,000	
2	9,290	710	9,522	478
3	9,298		8,117	1,405
4	5,964	3,334	7,047	1,070
5	10,440		10,308	
6	10,450		10,395	
7	4,545	5,905	4,605	5,790
8	16,429		15,407	
Total DEFE		9,949		8,743

Simulation Characteristics

In all FORPLAN forest planning models, one can find examples of constraints and initial conditions that affect the temporal and spatial application of harvests. In this study, three factors present in all (or at least nearly all) FORPLAN models that might be expected to interact with the DEFE are selected for analysis with the case study model:

1. Constraints to assure the maximum regeneration harvest size of 40 acres for both existing and regenerated stands.
2. A modification of the land base to reflect limited previous harvesting.
3. More realistic yield streams with thinning options.

This and all other analyses described below are carried out for eight planning iterations.

Regeneration Harvest Size Constraint

To satisfy the NFMA requirement that all regeneration harvests be not larger than 40 acres, a set of constraints was applied to the base model which guarantee that not more than 25% of an analysis area could be harvested in any one cutting period.[3] This constraint set is reason-

[3] *Jim Merzenich of the Region 6 Regional Office of the Forest Service indicated that, in his experience, these represent a lower limit to the spatial and temporal dispersion constraints applied in forest planning models for Forest Service Regions 1 (Northern) and 6 (Pacific Northwest). Although these constraints often do not occur in exactly this form, the net effect is the same.*

able if analysis areas occur in large contiguous blocks and it is widely applied in forest planning models.

The results of these simulations (table 2) show that the spatial dispersion constraints have a major impact on the DEFE. The base solution has three expressions of the DEFE, during planning iterations 2, 4, and 7, for a total of 9,949 mbf. When the spatial dispersion constraints are applied there is only one expression of the DEFE, in planning iteration 6 (2,580 mbf). The fact that the departure occurs far into the future when the spatial constraints are applied is both predictable and important. It is predictable because spatial constraints ration each analysis area's harvest over at least 4 cutting periods. It is important because a great deal of uncertainty is associated with events more than 50 years in the future even without the DEFE. In other words, the significance now of a DEFE that far into the future may not be all that high.

The columns for total revenue also show a more stable pattern with the spatial dispersion constraints than in the base runs. This suggests that, although (as shown in table 2) the dispersion constraints are quite expensive in present value terms, they assist not only in distributing harvesting activities spatially, but also in distributing revenue temporally.

Previous Harvesting Constraints

Few, if any, national forest planning units exist where previous harvesting has not occurred. In addition, because of natural catastrophes such as disease and fire, forests composed entirely of old-growth seldom occur. These factors can have a significant impact on the DEFE. Recall that if nondeclining yield constraints are imposed, the DEFE occurs when a harvest scheduling model uses negatively valued harvests to bridge the gap between profitable early old-growth harvests and profitable regenerated stands. This gap can also be bridged in mixed age forests by harvesting stands that are young at the start of the planning horizon.

Prior harvesting activities that modify the age structure of the forest will likely display additional characteristics that will reduce the DEFE. The areas where previous harvests have occurred will tend to both produce more valuable timber and have lower harvesting costs, thereby interacting with the DEFE in two ways: (1) the number of available high-value, old-growth stands will be reduced, thus reducing the potential for the DEFE to occur; and (2) the stands harvested before the first planning iteration would tend to be more productive and thus have shorter rotation ages for the regenerated timber. These shorter rotation ages would provide harvests sooner, thus tending to fill the gap between old-growth and regenerated stands.

To simulate this situation, the land base in the base model was modified to reflect assumed harvesting of 200 acres of each of the most profitable analysis areas (1 and 2) in each of the two preceding decades. This harvest of 400 acres per decade is significantly less than the amount that would be cut under strict area control (where 5,000/7 = 714 acres final harvested per decade) and also less than the amount that could be cut if only lands that are expected to be profitable in the future are harvested (where 4,000/7 = 571 acres final harvested per decade). Selecting the previous harvests from only the better sites is consistent with the idea of previous exploitation, conducted under the premise that meeting timber harvest targets while operating within a budget was the driving objective. Previous harvesting for only two decades was assumed because it is representative of conditions on many national forests.

Table 3 gives the results of the simulations with the land base modified and, to facilitate comparison, includes the results of the base model. The modified land base runs contain two departures attributable to the DEFE: one in planning iteration 2 (1,222 mbf) and one in planning iteration 7 (1,175 mbf), with a total DEFE of 2,397 mbf. This modification of the base model, which imitates existing conditions on many forests, shows considerable reduction of the DEFE, especially late in the conversion process. On the other hand, the harvest

Table 2.—First-period comparison with spatial dispersion constraints added (volumes are mbf).

Planning iteration	Spatial dispersion model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	6,068	0.651		10,000	1.532	
2	7,500	1.088		9,290	1.389	710
3	7,500	1.540		9,298	1.351	
4	10,080	2.169		5,964	0.736	3,334
5	10,080	1.636		10,440	1.840	
6	7,500	1.209	2,580	10,450	1.058	
7	7,500	1.209		4,545	0.460	5,905
8	13,875	4.584		16,429	7.575	
Totals	70,111	14.086	2,580	76,416	15.941	9,949
Revenue present net value		3.023			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 3.—First-period comparison of the base model with the same model with a modified land base to reflect previous harvesting (volumes are mbf).

Planning iteration	Modified land base model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	6,000	0.919		10,000	1.532	
2	4,778	0.767	1,222	9,290	1.389	710
3	7,215	1.048		9,298	1.351	
4	7,222	0.685		5,964	0.736	3,334
5	14,259	1.736		10,440	1.840	
6	14,895	4.507		10,450	1.058	
7	13,720	4.390	1,175	4,545	0.460	5,905
8	13,720	4.988		16,429	7.575	
Totals	81,817	19.040	2,397	76,416	15.941	9,949
Revenue present net value		3.173			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 4.—Yield table to demonstrate the impact of thinnings and more realistic yield streams on the DEFE (volumes are mbf).

Age	Stand volume (no thinning)	Thin every 20 years		Thin every 30 years	
		Thin	Volume	Thin	Volume (before thinning)
10	0		0		0
20	0		0		0
30	10		10		10
40	13		13		13
50	17	4	17		17
60	21		17	5	21
70	25	4	21		20
80	28		21		24
90	31	4	25	5	27
100	34		25		25
110	36	4	28		28
120	38		27	5	31
130	39	4	30		29
140	40		29		32

decline in the second planning iteration could be of considerable significance. As will be seen below, occurrences of the DEFE are delayed when a more realistic forest planning situation is simulated; at least this was so for this case study.

Using Alternative Yield Streams

Whereas one would expect that the two modifications to the base model discussed above would reduce the DEFE, the effect of more realistic yield streams (i.e., those showing net growth) or of prescriptions that include thinning are less predictable. On many national forests, thinnings are used extensively on the more productive stands. The model could conceivably use these intermediate harvests to bridge the gap between early profitable harvests and the final harvest of regenerated stands, resulting in a smaller DEFE. These thinnings also could be used to raise harvest levels during all planning iterations while leaving the DEFE essentially unchanged. In addition, unprofitable thinnings could result in an even greater DEFE. For these reasons the simulations presented in this section should be viewed as an example rather than as a general evaluation of the impact of thinnings on the DEFE.

Old-growth yields were not changed. We still assumed that the forest is composed of stagnant stands with inventory of 15 mbf per acre. The new yield streams for regenerated stands, all showing growth over time, are presented in table 4. The nonintensive management regime produces 10 mbf at 30 years, 25 mbf at 70 years (the same as in the original example), and reaches 40 mbf at 140 years. This yield stream reaches maximum mean annual increment at 70 years (the same as in the original example), the youngest age for which regeneration harvests are defined. Two thinning regimes are included. One has initial entry at age 50, additional entries every 20 years, and 4 mbf harvest per entry. The other thinning regime has initial entry at age 60, additional

entries every 30 years, and 5 mbf harvest per entry. The minimum rotation age is 70 years in both regimes. The price of sawtimber was unchanged from previous simulations, and cost of thinning harvest was assumed to be 20% higher than clearcut cost, which was also unchanged.

The results of simulations using these yield estimates and prescription options are presented in table 5. This example clearly demonstrates that profitable thinning options can be selected to bridge the gap without necessarily reducing the DEFE. The harvest in the later planning iterations (4–8) is increased somewhat, and the total DEFE of 10,749 mbf is slightly higher than the base model DEFE of 9,949 mbf.

A More Realistic Forest Planning Model Simulation

To more closely simulate a realistic forest planning model, the first two modifications (harvest size constraints and previous harvesting) were incorporated in the same model. The third modification was not included because of the arbitrariness of using any specific yield stream and its associated cost assumptions. While this model more closely corresponds to an actual planning situation, it is important to recognize that, in reality, both many more types of constraints and a land base with more age, species, and productivity classes would be encountered.

The simulation results for this model are presented in table 6. The DEFE did not occur in this model until planning iteration 7, and then it was quite minor (212 mbf). In planning iteration 8, a relatively severe DEFE of 3,748 mbf occurred, after which (not shown in the table) the harvest returned to a level just below that of planning iteration 7. The sharp drop in planning iteration 8 resulted because of two factors. First, a 250-acre analysis area was the only land harvested in planning iteration 1, so only 250 acres of regenerated stands were available for harvest seven decades later. Second, the acres regenerated before the first iteration of forest planning had been harvested in iterations 6 and 7, thus leaving no previously regenerated lands available for harvest.

Table 5.—First-period results of model simulations using modified yield information (volumes are mbf).

Planning iteration	FORPLAN base model		Modified yields model	
	Harvest	DEFE	Harvest	DEFE
1	10,000		10,000	
2	9,290	710	9,890	110
3	9,298		6,182	3,708
4	5,964	3,334	5,480	702
5	10,440		13,455	
6	10,450		13,074	381
7	4,545	5,905	7,226	5,848
8	16,429		15,655	
Total DEFE	76,416	9,949	80,962	10,749

Applying a Harvest Floor

Simulations to evaluate use of a first cutting period constraint (a harvest floor) were run for four of the models. These constraints require that first-period harvest be at least as great as first-period harvest in the previous planning iteration for each of the eight iterations. The models to which a harvest floor was applied are:

1. The base model (table 7).
2. The model with spatial dispersion constraints (table 8).
3. The modified land base model (table 9).
4. The more realistic forest planning model with both spatial dispersion constraints and modified land base (table 10).

For ease of comparison, the simulation results when no floor is imposed are also repeated in the tables showing simulation results. The analysis demonstrates the cost for each of the models tested of satisfying the intent of both the Multiple-Use Sustained-Yield Act (P.L. 86–517) and the NFMA which direct that national forests provide a nondeclining flow of wood products to society over time (i.e., the cost of eliminating any possibility of a DEFE).

The cost of imposing the harvest floor as measured by the present value of actions taken in the first eight planning iterations was quite modest in all of these models. The low magnitude of this cost can be explained by the financial characteristics of analysis area 5 which could never be harvested profitably. However, it did not have a large negative value when it was finally harvested because, after 50 years of stumpage value increases, the net harvest value per acre in decades 6, 7, and 8 was a loss of only $282. The relative magnitude of the present value loss for the solutions presented can be further explained by the fact that many of the occurrences of the DEFE seen in the earlier simulations, and that are prevented by the harvest floor, happen during later planning iterations.

Table 7 shows that applying a harvest floor to the base model results in a loss of present net value of only 1.11%. However, the revenue figures by planning iteration clearly show the problem that McQuillan emphasizes. In order to maintain harvest levels in planning iteration 7, the only available timber is in the unprofitable analysis area (AA5). This results in a negative cash flow of $188,000 for planning iteration 7, a situation that may be unacceptable. In general, such large decreases in revenue over time could be disruptive to the Forest Service.

Table 8 presents analogous information for the spatial dispersion analysis. The proportionate loss in present value associated with application of the timber harvest floor is 0.33%, or less than one-third of the loss present in the base model. The revenue flows in these simulations are much more uniform from iteration to iteration than are those in the base model. Although 172 acres of analysis area 5 are harvested at a loss in each of iterations 6 and 7, the spatial dispersion constraints

Table 6.—First-period comparison of the base model with the more realistic forest planning model used by the Forest Service (volumes are mbf).

Planning iteration	Forest planning model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	3,750	0.574		10,000	1.532	
2	6,592	1.010		9,290	1.389	710
3	6,593	0.924		9,298	1.351	
4	6,600	0.968		5,964	0.736	3,334
5	7,500	0.872		10,440	1.840	
6	14,740	4.942		10,450	1.058	
7	14,528	4.614	212	4,545	0.460	5,905
8	10,780	3.435	3,748	16,429	7.575	
Totals	71,083	19.207	3,960	76,416	15.941	9,949
Revenue present net value		2.887			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 7.—First-period comparison with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	10,000	1.532		10,000	1.532
2	9,290	1.389	710	10,000	1.450
3	9,298	1.351		10,000	1.453
4	5,964	0.736	3,334	10,000	0.949
5	10,440	1.840		10,000	1.162
6	10,450	1.058		10,000	1.012
7	4,545	0.460	5,905	10,000[2]	–0.188
8	16,429	7.575		16,667	7.687
Totals	76,416	15.941	9,949	86,667	15.057
Revenue present net value[3]		3.597			3.557

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*667 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 1.11%.*

Table 8.—First-period comparison with spatial dispersion constraints with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	6,068	0.651		6,068	0.651
2	7,500	1.088		7,500	1.088
3	7,500	1.540		7,500	1.540
4	10,080	2.169		10,088	2.169
5	10,080	1.636		10,080	1.636
6	7,500	1.209	2,580	10,080[2]	1.160
7	7,500	1.209		10,080[2]	1.160
8	13,875	4.584		13,875	4.584
Totals	70,111	14.086	2,580	75,271	13.988
Revenue present net value[3]		3.023			3.013

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*172 acres of analysis area 5 are harvested at a loss in each of these planning iterations.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 0.33%.*

Table 9.—First-period comparison of the modified land base model with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	6,000	0.919		6,000	0.919
2	4,778	0.767	1,222	6,000	0.870
3	7,215	1.048		6,000	0.872
4	7,222	0.685		7,222	0.685
5	14,259	1.736		14,250	1.736
6	14,895	4.507		14,250	4.443
7	13,728	4.390	1,175	14,250	4.442
8	13,720	4.988		14,250[2]	4.532
Totals	81,817	19.040	2,397	82,222	18.499
Revenue present net value[3]		3.173			3.136

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*285 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 1.17%.*

Table 10.—First-period comparison of the more realistic forest planning model with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	3,750	0.574		3,750	0.574
2	6,592	1.010		6,592	1.010
3	6,593	0.924		6,593	0.924
4	6,600	0.968		6,600	0.968
5	7,500	0.872		7,500	0.872
6	14,740	4.942		14,740	4.942
7	14,528	4.614	212	14,740	4.610
8	10,780	3.435	3,748	14,740[2]	3.410
Totals	71,083	19.207	3,960	75,255	17.310
Revenue present net value[3]		2.887			2.886

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*250 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 0.03%.*

conserve enough valuable timber and limit the harvest of stands that cannot show a profit to levels that still provide significant ($1.16 million) revenue in these planning iterations.

Table 9 presents analogous information for the modified land base simulations. The proportionate loss in present value associated with application of the harvest floor is the largest of the four models examined. The reason the loss is so large relates to the early timing of the largest expression of the DEFE. Initially there is a reduced amount of highly profitable timber; consequently, a departure of 1,222 mbf occurs in planning iteration 2. The effect of the floor increases the harvest so much above optimal levels early in the process that the effects of discounting cause a relatively large impact on the revenue present value. However, the sequence of cash flows did not display the dramatic decreases shown in tables 7 and 8.

Table 10 provides analogous information for the more realistic forest planning model simulations. The proportionate reduction in present value resulting from application of the harvest floor was quite small, being only 0.03% as compared with a reduction of 1.11% in the base model. In addition, the revenue was fairly stable over time in the sense that large proportionate decreases were not observed.

Two inferences can be made from the results of the harvest floor simulations. First, even when the harvest floor is applied, the nature of the constraints in Forest Service models insures that first period revenues will to be more uniform than is the case in the unconstrained model portrayed by McQuillan (tables 8–10 vs. 7). Second, these constraints also result in a significant reduction in the cost of the harvest floor in the simulation most representative of Forest Service planning models (table 10 vs. 7).

SUMMARY AND CONCLUSIONS

The case study developed in this report clarifies several aspects of the DEFE. Although the DEFE can and will occur in future national forest plan updates, its expected magnitude can be significantly reduced by the characteristics of the Forest Service planning process. Three factors were found to have a large impact in nearly all forest planning models:

1. Spatial and temporal dispersion constraints tend to apportion harvest from an analysis area over several cutting periods, rather than allowing immediate complete exploitation.
2. The initial timber age class distribution typically includes many stands regenerated before the start of the planning process. These become available for harvest in the decades between early harvest of profitable old-growth stands and eventual harvest of stands regenerated during the first or later iterations of planning.
3. Many forest plans assume increasing product prices in the early part of the planning horizon. This allows additional analysis areas to become profitable during the early decades of the planning horizon, helping to bridge the potential harvest gap between profitable old-growth liquidation and harvest of regenerated stands.

In addition, the average forest planning model is very highly constrained in order to address local issues, and many of these constraints may also interact to inhibit the DEFE. Because of the local nature of these issues, their impact was not (and could not be in general) evaluated in this study.

One factor we expected would reduce the DEFE may not, in general, do so. FORPLAN models often select many prescriptions that involve thinning harvests. In addition, these thinnings are often concentrated in the cutting periods between liquidation of the old growth and the final harvest of regenerated stands. Thus, it seems plausible that the use of profitable thinnings can bridge the gap between old-growth liquidation and terminal harvest of regenerated stands. The case study developed above shows that extensive use can be made of profitable intermediate harvests without significantly reducing the DEFE.

The case study demonstrates the relationship between certain aspects of the planning process used by the Forest Service and the DEFE. This increased understanding can be used to identify forests at high risk of severe DEFE. The potential problem should be recognized and addressed in the planning process.

FORPLAN formulations that directly address the option of departures are needed. The current approach in forest planning is to allow limited increases or decreases in planned periodic harvest levels. Figure 1 shows examples of this type of alternative (alternatives M and N) for the Kootenai National Forest. However, these "limited departures" are often not viable options. In the absence of other constraints, and with a predominantly old-growth forest, the harvest scheduling model would select a high initial harvest level followed by a series of harvest reductions in later cutting periods. This sequence of harvest levels would allow much faster liquidation of the old-growth, but at the cost of repeated departures. The repeated departures would be very hard to justify in practice.

A more appropriate analysis could be developed by future research to address the question of planned departures. There are several desirable characteristics for a more robust analysis of departures. First, the analysis should address the option of allowing future departures within the current iteration of planning. Second, the approach should allow specification of the maximum number of departures that would be acceptable. In practice, this number would be quite small (one or two), rather than the repeated harvest reductions resulting from the current "limited departures" analysis. Third, the timing of the departures should be optimally scheduled. And, fourth, the analysis should allow the maximum magnitude of each departure to be specified.

A much more complete and appropriate analysis of the question of future departures would be possible if a FORPLAN option with these characteristics were available. Analysis using this tool could directly address the DEFE. In addition, other vexing issues of the forest planning process, such as the allowable cut effect and estimating the opportunity cost of the nondeclining yield constraints, could be addressed.

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The declining even flow effect (DEFE) identified by McQuillan (1986) may be a serious flaw in the planning process used by the USDA Forest Service. This report addresses the relationship between this process as it is used to develop FORPLAN models and the DEFE. A case study is used to show that certain items common to all FORPLAN models reduce the magnitude and number of occurrences of the DEFE.

Keywords: Timber harvest scheduling, linear programming

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